Prince George's County Department of Parks and Recreation,
Division of Maintenance and Development

Direct Annual Carbon Dioxide Emissions from Mobile Combustion Sources

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Executive Summary

Reducing carbon emissions is necessary to mitigate the consequences of human-driven global climate change. Mobile sources of carbon emissions, such as vehicles and equipment, are a significant driver of the atmospheric warming the planet is experiencing. Therefore, they must be greatly decreased in a short timeframe to ensure a livable environment for future generations.

All across the globe, actions are being taken at various scales to transition from fossil fuels as the world's dependent energy source. The responsibility for transition, like the consequences of climate change, must be shared by everyone. However, to date the US has emitted more CO_2 than any other country in history and must take the lead in changing course.

As in many other parts of the country, Maryland will experience the effects of anthropogenic climate change, such as sea level rise and saltwater intrusion along the Chesapeake Bay coastline. Mitigation efforts within the state will need to focus on accessible mobile sources of carbon emissions, such as the vehicle fleets and equipment used in municipal operations, to bring about sizable reductions in carbon emissions and to serve as a model for others to follow.

In this context, the Division of Maintenance and Development in the Prince George's County Department of Parks and Recreation sought to obtain a profile of its current mobile carbon emissions along with guidance on ways to reduce those emissions by 50 percent within 10 years.

Direct mobile carbon emissions from sources used by the Division were calculated by combining information on fuel quantities with research into fuel consumption rates and emissions coefficients. This analysis resulted in an estimated baseline of 909.3 metric tons of CO_2 being emitted by 88.4 percent of the inventory items. The remaining 11.6 percent of the inventory, equipment for which there was insufficient information to calculate emissions, accounted for 1.7 percent of total logged equipment usage hours. Vehicles accounted for two-thirds of the total calculated CO_2 emissions.

Strategies such as planning efficient work and equipment selection, reducing idling and installing fuel consumption monitoring systems are immediate cost-effective approaches that can be implemented to reduce carbon emissions. Longer term reduction strategies are presented in two options: using biodiesel or switching to electric powered vehicles and equipment. The second option is seen as the most effective approach for meeting the Division's 50 percent reduction goal, while also building capacity for further emissions reductions. Implementing both immediate and longer-term strategies will allow the Division to more accurately calculate annual carbon emission baselines in the future, track its progress, and be in position to achieve more stringent carbon reduction goals beyond those established for 2030.

Introduction

The operations of many vehicles and equipment consume fossil fuels to produce the energy that powers these items. It is estimated that there are 1.2 billion vehicles being driven throughout the world, and as of 2019, only 7.2 million (approximately 0.6 percent) of these vehicles are electric (International Energy Agency, 2020). Greenhouse gases (GHGs) are the byproducts of fossil fuel consumption; CO_2, CH_4, and N_2O accumulate in the Earth's atmosphere. But compared to CO_2, the release of CH_4 and N_2O have relatively small contributions to the overall production of GHGs. The EPA reports that for on-road mobile combustion sources less than 15 years old, only about one percent of their emissions are CH_4 and N_2O. And for even older on-road gasoline powered vehicles, only about five percent of their overall emissions are CH_4 and N_2O (U.S. Environmental Protection Agency, 2016).

The accumulation of these gases contributes to atmospheric warming, which is expected to cause temperatures to increase from 2.5 to 10 degrees Fahrenheit throughout the 21st century (NASA, 2020). The continual warming of oceans will lead to the melting of nearly all of the ice in the Arctic Ocean by 2050. This, in combination with thermal expansion, is expected to contribute to global sea level rise of one to eight feet by 2100 (NASA, 2020).

In an effort to mitigate their climate impacts, many governments throughout the world are committing to reduce mobile combustion source emissions through the use of electric equipment and vehicles and by transitioning from gasoline and diesel fuels to cleaner alternatives such as biodiesel and natural gas. A 2015 study conducted by the International Council on Clean Transportation showed that the combined impact of this will be 30 million electric vehicles in use by 2025. By 2030, the global impact of this shift would result in a decrease of 113 million metric tons of CO_2 produced per year (Lutsey, 2015).

Within the United States, the EPA reports that "the transportation sector is one of the largest contributors to anthropogenic greenhouse gas emissions." (U.S. Environmental Protection Agency, 2019). Studies throughout the country show the extent to which emissions reductions from mobile combustion sources can remediate the speed and extent to which climate change will occur. For instance, a 26 to 30 percent reduction of total US transportation emissions could be achieved by 2050 if electric light-duty vehicles were able to take over 56 percent of the new vehicle market (U.S. Department of Transportation, 2010).

The Maryland Commission on Climate Change's 2008 *Comprehensive Assessment of Climate Change Impacts in Maryland* reported on expected climate change impacts throughout the state. The analysis shows that as a result of increased atmospheric GHG concentrations, Maryland will experience a temperature increase of at least three degrees Fahrenheit by the middle of the 21st century. Additional warming throughout Maryland later in the century directly depends on "the degree of mitigation of greenhouse gas emissions," and this increase could be as severe as nine degrees Fahrenheit (Boesch, 2008).

Further state level implications include changes to precipitation patterns, extended droughts, and heat waves. Sea level rise has already had a lasting impact on the state given its 3,100 miles of shoreline, and Maryland is expected to be the "fourth most vulnerable state to suffer the effects of sea-level rise associated with climate change" in the US (Beck, 2020). Since the 1600s, the water level of the Bay has already risen by three feet, and it is expected that another two feet of sea level rise could be seen by 2100 (West, 2019). Restoration of key natural resources in Maryland, like the Chesapeake Bay and its surrounding watershed, will also be more difficult to achieve due to increased stratification and water acidity that would affect the shellfish survival, which are keystone species in these marine areas (Boesch, 2008).

In response to these expected issues, the State of Maryland passed the Greenhouse Gas Emissions Reduction Act (GGRA) in 2009 (Beck, 2020). This Act requires a 25 percent reduction in GHG emissions from 2006 levels by 2020. In 2015, the Maryland Department of the Environment reported that the State was on target to exceed the emissions reduction goal set forth in the 2009 legislation. This led to the GGRA being amended in 2015 with a new target—a 40 percent reduction in GHG emissions from 2006 levels by the year 2030 (Beck, 2020).

According to the World Resources Institute, Maryland currently leads the nation in reducing GHG emissions (38 percent) while promoting economic growth (18 percent of GDP) (Beck, 2020). In Prince George's County, the current goal is to reduce county-wide carbon emissions to 80 percent below 2008 levels by 2050. Recent assessments show that by 2015, the county had reduced its own GHG emissions by 12 percent from 2005 levels, which was a decrease from 11.3 million MT of CO_2 to 9.9 million MT of CO_2 (Prince George's County Sustainable Energy, 2020).

The Maryland-National Capital Park and Planning Commission (M-NCPPC) Department of Parks and Recreation in Prince George's County is responsible for operating and maintaining 27,000 acres of parkland within the county. Within this agency, the Division of Maintenance and Development is responsible for all major maintenance projects, including carpentry, electrical, HVAC, masonry, painting, plumbing, and welding work. The Division also manages the renovation of athletic fields, vehicle repairs, maintenance inspections, and horticulture and forestry services (Prince George's County, n.d.). During the course of this work, a fleet of 233 individual vehicles and pieces of equipment are used to accomplish the tasks necessary to keep lands and facilities operational. Due to the increased need to meet state and county CO_2 emissions reductions standards, the Division of Maintenance and Development intends to implement changes within its fleet.

More specifically, the Division seeks to decrease carbon emissions from the mobile sources in its inventory by 50 percent by 2030. Currently the division doesn't have a clear accounting of the carbon emissions it produces or a strategy for reducing the carbon it emits. Given the Division's operational needs, a 2019 study provided a baseline estimate of the direct carbon emissions produced by its vehicles and equipment. The study also investigated a series of approaches to achieve the desired 50 percent reduction in carbon emissions by 2030.

A secondary goal of the study was to provide a robust methodology to investigate carbon emissions from operations for which fuel consumption information is not always available. The implications and findings of this study may be valuable to companies and municipal operations that are considering crafting their own carbon emissions reductions plans.

Objectives

To fulfill the needs of the Division of Maintenance and Development, this project was divided into two objectives. The first was to obtain, analyze, research, and organize a complete inventory of all fuel-consuming vehicles and equipment used by the Division of Maintenance and Development. The inventory was used to calculate an estimated baseline of direct annual carbon emissions from mobile combustion sources in the Division between January 1, 2019 and January 1, 2020.

The second objective was to provide the Division with recommendations for reducing 2019 baseline carbon emissions by 50 percent within the next ten years.

Methodology and Research Approach

At the start of the project, the Division of Maintenance and Development provided an inventory of all mobile combustion sources used in 2019. The inventory included the number of miles driven in the 2019 calendar year for the vehicles and the number of hours of operation for the equipment. The inventory also included the vehicle VIN numbers and the equipment manufacturer's serial numbers. The model and year for each inventory item was provided, however in some instances, it was necessary to research individual items to identify a specific version of a model or to obtain the specific information needed to calculate carbon emissions.

Inventory items were sorted into three categories based on how their annual use was documented; each category was subdivided into three subcategories based on the use or function of the inventory item (Figure 1). In the case of the vehicles, AutoZone's online vehicle VIN database (Autozone, 2020) was used to categorize each type of vehicle as either a "car," "truck," "van," or "large/heavy-duty vehicle."

Annual carbon emissions were determined from their annual fuel use and a carbon emissions coefficient obtained from the U.S. Energy Information Administration (EIA) for the fuel type powering the inventory item. The coefficients used were 10.16 kg CO_2 per gallon diesel, 8.89 kg CO_2 per gallon of gasoline, and 5.76 kg CO_2 per gallon propane (U.S. Energy Information Administration, 2016). In instances where the annual fuel amount could not be obtained from the

Division's fuel logs, other approaches were used to estimate annual fuel amounts. These approaches were limited to items in the two equipment categories and are described below.

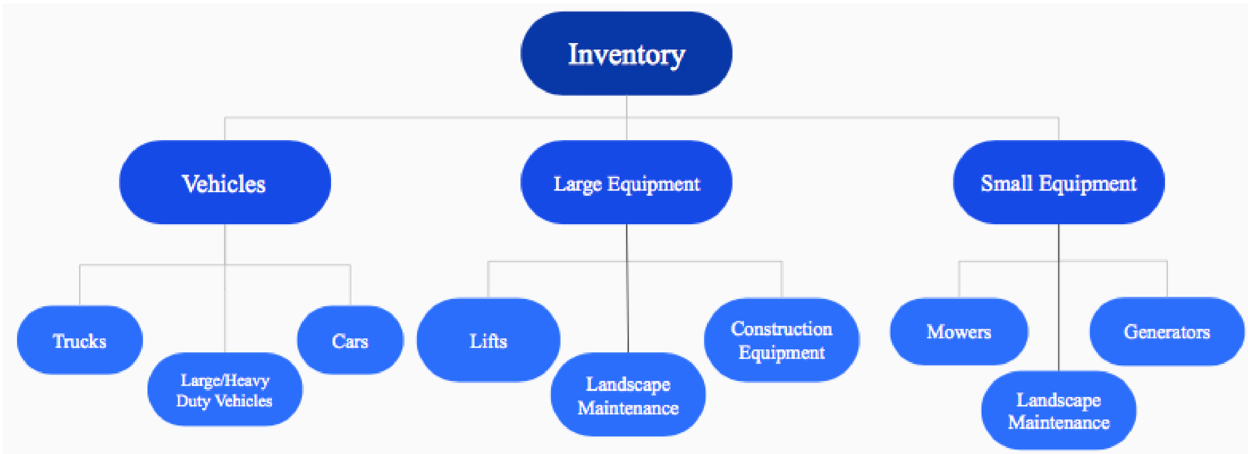

Figure 1: Inventory items by category

Fuel log data was used to multiply fuel quantity by the fuel type's CO_2 emissions coefficient to get kilograms of CO_2 produced. If fuel log data wasn't available, an estimate of the annual fuel quantity was used for CO_2 calculations. The fuel quantity consumption estimates first focused on obtaining an estimated hourly fuel use rate for equipment, then multiplying this number by the annual hours of operation of the equipment. Fuel consumption rates (liters per hour or gallons per hour) were found through manufacturer websites, owner's manuals, parts manuals, by contacting manufacturers, and in online forums about specific equipment. The primary source for fuel consumption were owners' manuals. If the manual didn't list fuel consumption ratings, equipment forums and equipment-related websites were used as sources for estimates.

If fuel consumption rates still couldn't be estimated, we asked the Division's field level workers to answer a questionnaire about frequency with which equipment was refilled by users. For equipment in the inventory without any annual fuel consumption data, a final approach used was to estimate an hourly fuel consumption rate based on the engine's horsepower. This was done using a fuel consumption chart available from the Barrington Diesel Club (BDC, 2017) and was applied to some diesel-powered equipment in the large equipment category. This approach assumed that the specifically rated engine horsepower was used to perform the task required of the piece of equipment.

Carbon Emission Reduction Strategies: Continued Research

Developing the plan of action to reduce CO_2 emissions from 2019 levels was based in part on research into emissions reduction strategies implemented in counties and parks departments across the country. These initiatives provided guidance on tactics that have succeeded in fleet equipment and vehicles in similar settings. For example, based on a report from the National

Recreation and Park Association, counties and cities such as Chicago, IL have switched to alternative fuel sources for vehicles and equipment, which has been effective in reducing carbon emissions in the local area (Watchwords & New, 2009). Additional strategies aimed at reducing vehicle and equipment emissions were derived using data from the EPA (Agency 2016), the Department of Energy (AVTA: Light Duty Alternative Fuel and Advanced Vehicle Data | Department of Energy, n.d.), and various manufacturer's websites (used to identify low- or no-carbon emissions models). This research and the results of the annual baseline emissions calculations were the basis for developing effective and specific recommendations to the Division of Maintenance and Development to reduce annual carbon emissions to 50 percent of 2019 levels by 2030.

Results

Direct carbon emissions were calculated for all but 20 pieces of inventory equipment. Neither direct fuel usage data from the Division nor source documents of fuel consumption rates for those 20 pieces were available. Collectively, 88.4 percent of the vehicles and equipment were accounted for in emissions calculations (Figure 2). The equipment not included in the emissions total represented 27.8 percent of all the equipment in the inventory (Figure 3). However, the number of hours for the missing equipment accounted for only 1.7 percent of the total hours for large and small equipment (Figure 4).

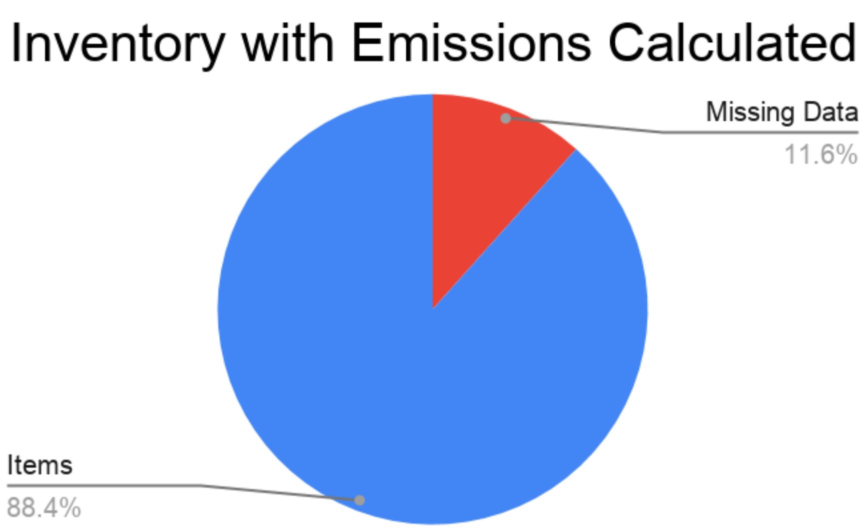

Figure 2. Percentage of inventory items included and excluded from carbon emission calculation

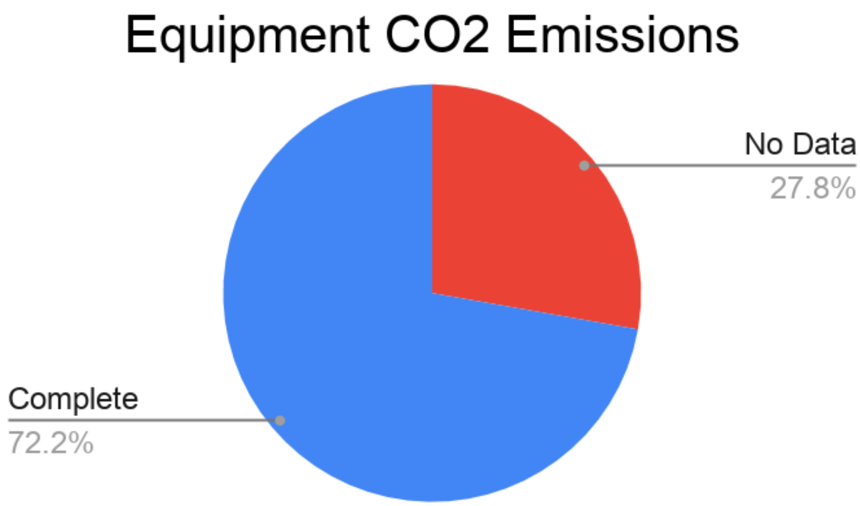

Figure 3: Percentage of equipment inventory on which emissions calculations were based

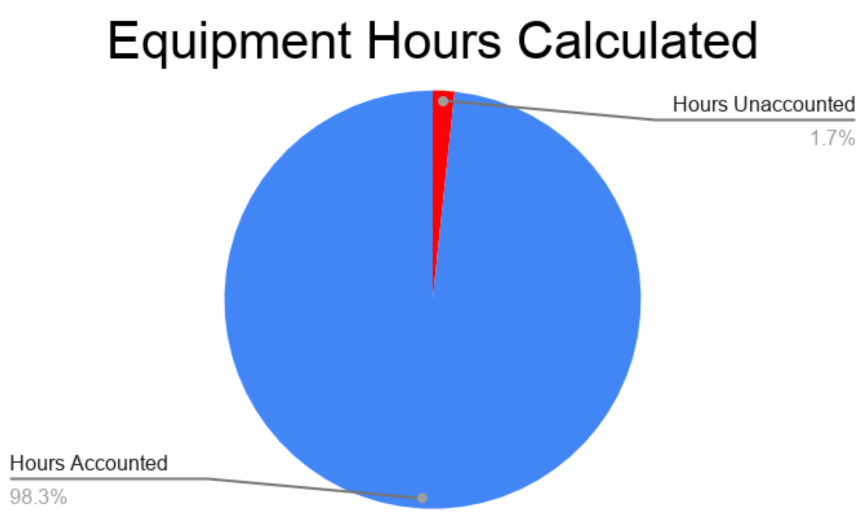

Figure 4: Percentage of equipment usage hours not accounted for in emissions calculations

The Division of Maintenance and Development's fleet produced 909.3 MT (or 2,004,690.455 lbs.) of CO_2 between January 1, 2019 and January 1, 2020 (Table 1). Fleet vehicles were responsible for 607.4 MT CO_2, 66.8 percent of the total emissions. Large and small equipment produced 301.9 MT CO_2, the remaining 33.2 percent of total CO_2 emissions (Figure 5). Furthermore, heavy-duty vehicles were 23.5 percent (213.7 MT) of total emissions, trucks 25.8

percent (234.6 MT), large equipment 30.7 percent (278.7 MT), and small equipment 2.5 percent (23.2 MT) of total emissions (Figure 6).

The highest emissions were produced by heavy-duty vehicles, trucks, and large equipment. The 33 heavy-duty vehicles make up 15 percent of the total inventory but are responsible for one quarter of the total emissions. Heavy-duty vehicles were 25.2 percent of the fleet (Figure 7) and contributed to 35.2 percent (229.4 MT) of vehicle emissions (Figure 8). This partially correlates with the large number of miles driven by large and heavy-duty vehicles, which was 19.7 percent, 159,497 miles throughout 2019 (Figure 9).

Direct Annual CO_2 Emissions

Table 1: 2019 direct annual CO_2 mobile emissions for the Maintenance and Development Division

Vehicles	Equipment	Total CO_2 Emissions
607.4 MT CO_2	301.9 MT CO_2	909.3 MT CO_2

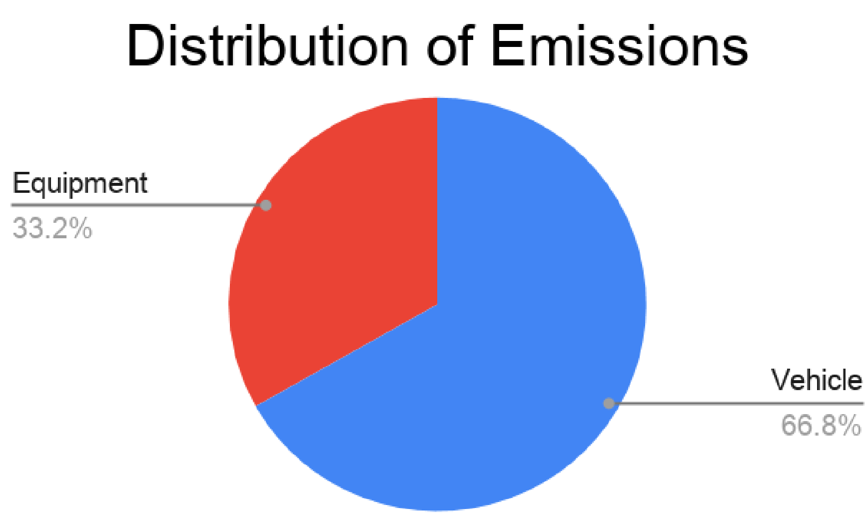

Figure 5: Percentage distribution of emissions produced by the equipment and vehicle categories in the Maintenance and Development Division fleet

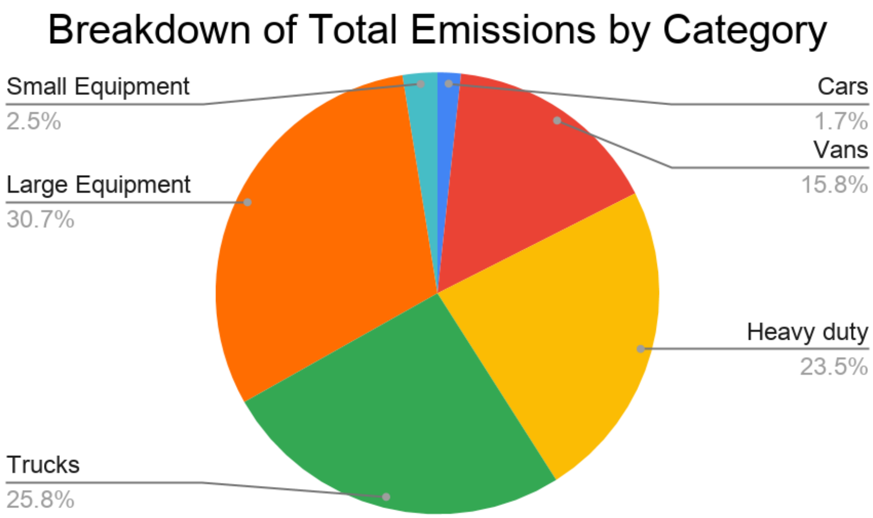

Figure 6. Subcategories of emissions by type

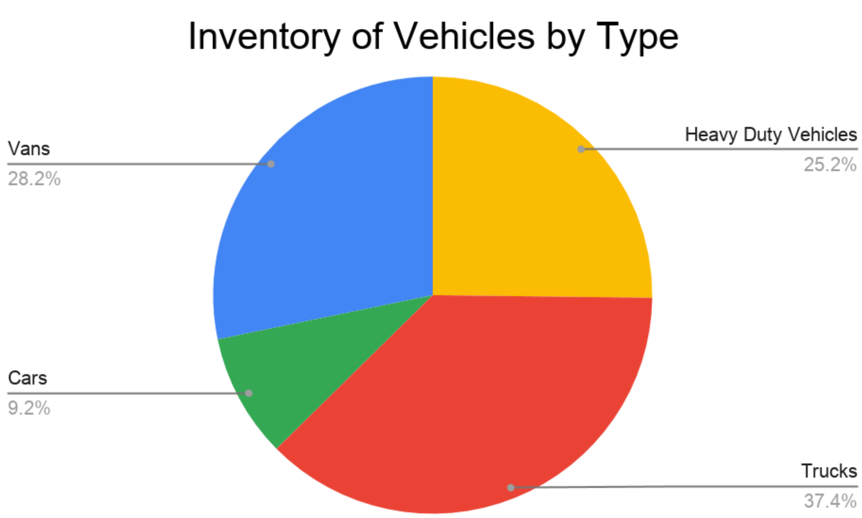

Figure 7: Inventory vehicles by type

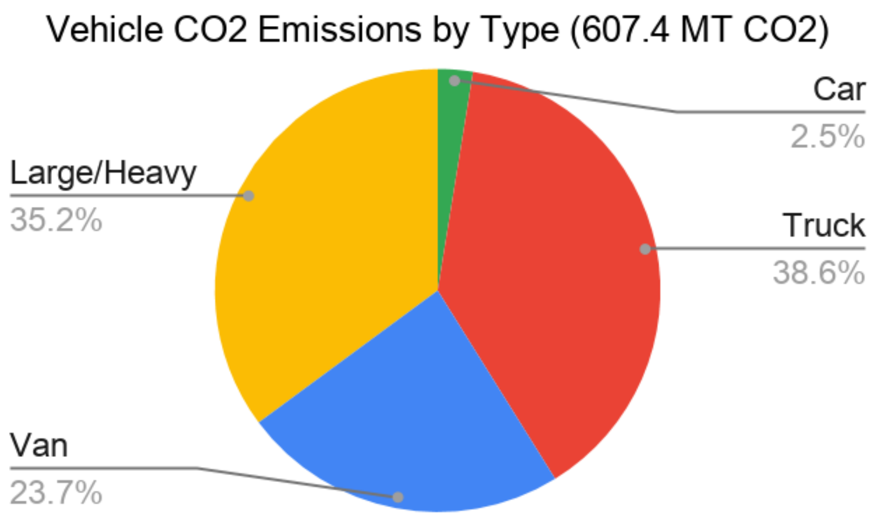

Figure 8: Vehicle CO_2 emissions by vehicle subcategories

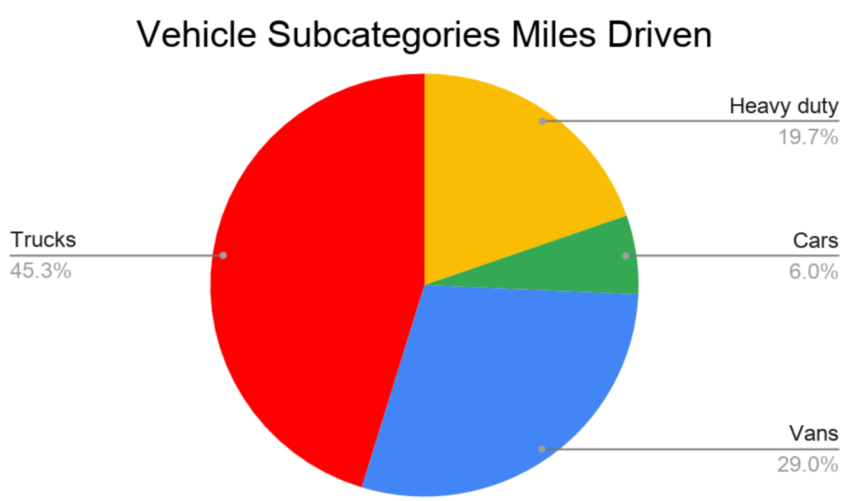

Figure 9: Miles driven, by equipment subcategories

Equipment makes up 33.2 percent (301.9 MT) of the inventory (Figure 5). In 2019, large equipment generated 92.3 percent (278.7 MT) of equipment emissions while small equipment generated 7.7 percent (23.2 MT) of the equipment emissions (Figure 10). Bulldozers and loaders contributed 29.2 percent and 19.2 percent of the total large equipment emissions, respectively (Figure 11). The "Other" category in the large equipment inventory includes lifts, rollers, graders, tractors, a chipper, and a grinder. In 2019, small equipment contributed 2.5 percent of total emissions, but mowers made up 89.7 percent (20.6 MT) of small equipment emissions (Figure 12). The remaining 10.3 percent of small equipment emissions came from utility vehicles

(1.1 MT), trail lights (0.98 MT), generators (0.14 MT), a stand-on aerator (0.069 MT), and a spreader (0.056 MT).

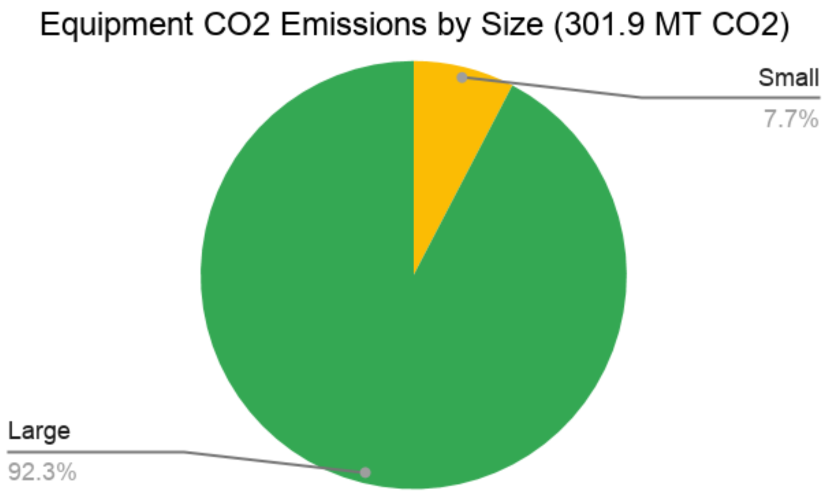

Figure 10: Equipment CO_2 emissions by broad subcategories

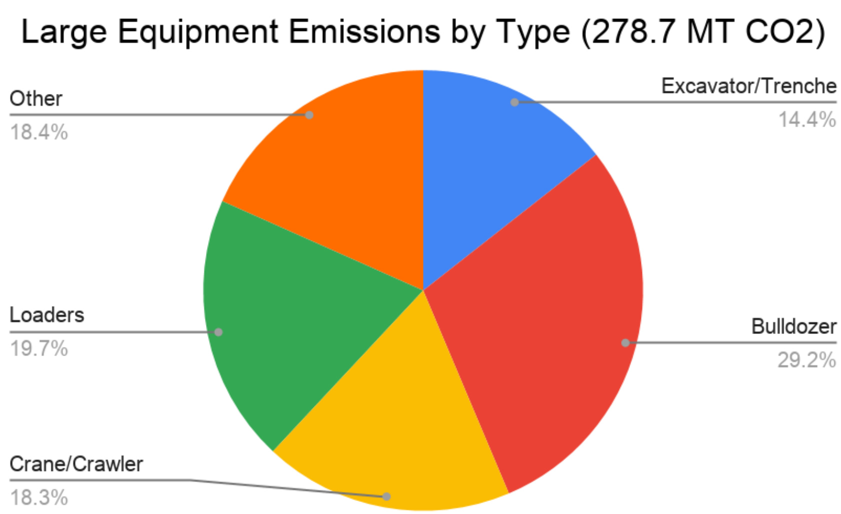

Figure 11: Total large equipment emissions by type

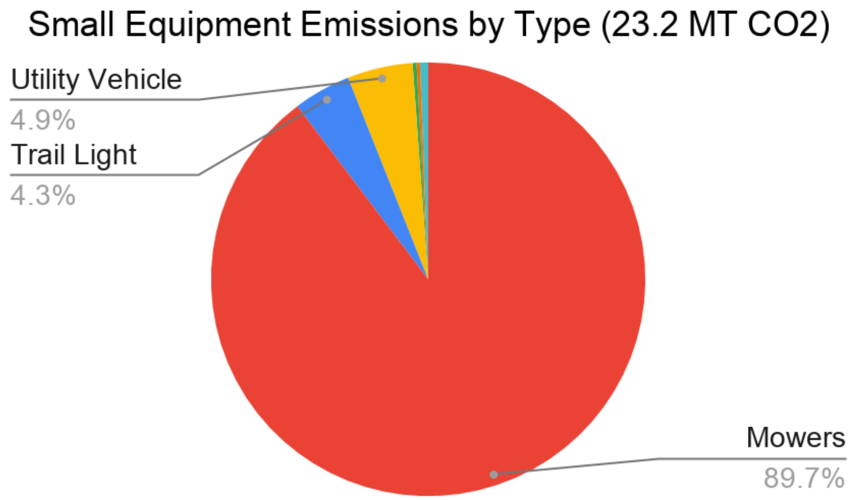

Figure 12: Total small equipment emissions by type

Carbon Emission Reduction Strategies

Numerous strategies can bring about a 50 percent reduction in carbon emissions from the 2019 baseline by 2030. The strategies can be broadly categorized as changes in practice, alternative fuel vehicles and equipment, and continued future investment. How these categories contribute to the goal of a 50 percent emissions reduction, and how they apply to Division of Maintenance and Development operations are explained below.

<u>Changes in Practice</u>

As noted above, in 2019, the Division of Maintenance and Development produced 909.3 MT of carbon emissions from vehicles and equipment, which is a relatively small number compared to the state of Maryland, which produced 28.59 million MT of carbon emissions from vehicles in 2014 based on research from the State's Greenhouse Gas Emission Inventory documentation (Maryland Department of Environment, 2014).

Perhaps the most efficient and effective strategy to decrease carbon emissions from a relatively small and local source of emissions, such as the Division of Maintenance and Development, is to change the standard use practices of vehicles and equipment. Many vehicle fleets and construction companies across the country operate with numerous inefficiencies that are almost entirely a direct cause of poor practice and use of equipment and vehicles. A paper by Business U.S. Cellular found that "For the first time in five years, Automotive Fleet's 2018 operating cost survey revealed that fleet operating costs have increased, due in part to higher fuel and maintenance costs" (Cellular, 2019).

Specifically, for the Division of Maintenance and Development, these practice changes can be sorted into three main categories that should be implemented to reduce emissions: efficient work planning and proper vehicle and equipment selection, reducing vehicle and equipment idle time, and establishing vehicle and equipment monitoring systems to continuously upgrade for efficiency. Improving the Division of Maintenance and Development's usage practices can reduce carbon emissions and cut costs for the Division to reach a 50 percent reduction by 2030.

Efficient Work Planning and Proper Vehicle and Equipment Selection

Construction companies and businesses with large vehicle and equipment fleets must focus on project planning including what vehicles or equipment to use to be as efficient as possible. The Division of Maintenance and Development undertakes various restoration and construction projects each year, which require precise planning and numerous vehicles and equipment to complete. Often, at a construction site, equipment like cranes and excavators are left idling or are used for a longer time periods than needed because of inefficient work planning.

Improved vehicle and equipment use can be a key factor in reducing CO_2 emissions. For example, if an excavator is only needed for three days of the construction process, the project planner should make an effort to not allow the excavator to be on site for more than three days and should actively ensure that the excavator is not turned on longer than needed. A study of CO_2 emissions produced by construction equipment found that with proper planning the operating time of excavators could be reduced by 10 and 20 percent, with a corresponding two to four percent reduction in CO_2 emissions (Sandanayake, 2015). While the reduction in emissions was small, the study demonstrated that proper planning can be an effective tool to reduce carbon emissions

Choosing the best piece of equipment is also crucial to reducing carbon emissions. For example, when choosing between cranes, project planning should opt for the crane with the closest load and horsepower specifications needed to complete the task. This strategy is effective in reducing emissions because using a piece of equipment with the appropriate horsepower uses less fuel emits less CO_2. A case study, Environmental Emissions of Construction Equipment Usage in Pile Foundation Construction Process, concluded that "when the power reduces by a percentage of around 22%, there is an emission reduction in the range of 7 to 10% with CO_2 emissions having the highest reduction" (Sandanayake, 2015). Overall, this change in practice can lower vehicle and equipment carbon emissions by nine to 12 percent if monitored and implemented correctly on all equipment and vehicles.

Reducing Vehicle and Equipment Idle Time

One of the most effective ways to reduce carbon emissions is by reducing the vehicle and equipment idle time. One study reported that reducing the idle time in a 24-vehicle fleet can save up to 600 gallons of fuel per year (Cellular, 2019). Using a production rate of 20.2 lbs. of CO_2eq per gallon of diesel; this is equivalent to a reduction of 5.5 MT of CO_2 per year (Curran, 2013).

One of the best ways to reduce idle times, particularly for the Division of Maintenance and Development, is to educate operators about reducing idling and other practices that can reduce carbon emissions. In fact, “Skilled equipment operators consume less fuel compared with less experienced and average operators per operating hour as skilled operators take good care of equipment, identify equipment problems in a timely manner, reduce idle time, follow correct working procedures, and operate equipment in the smartest and most cost-efficiency way.” (Fan, 2017).

The Division can establish more efficient operation practices by ensuring proper training for operators on specific pieces of equipment and provide salary incentives for operators with the most experience and good records. Visual reminders of why it’s important to reduce idling time, to not aggressively brake, and to not accelerate rapidly can also promote reduced fuel consumption.

Establishing Vehicle and Equipment Monitoring Systems

Establishing real-time data monitoring for vehicle and equipment carbon emissions and fuel usage is a major step toward reducing carbon emissions in the Division’s fleet. Data monitoring entails attaching equipment telematics to the engine to collect and store information on engine status, power output level, and speed acceleration. The retrieved data can be used to analyze the overall productivity and efficiency of the fleet inventory.

An Environmental Defense Fund study states that “Some ECM’s (Electronic Control Modules) can be modified to reduce fuel consumption by reducing top speeds, cutting idling, and lowering transmission RPM’s” (EDF, 2020). In a specific example, installing “LKQ [an aftermarket automotive parts supplier’s engine control modules] across the entire fleet, would mean a 5,300-ton reduction of GHG emissions” (EDF, 2020). The installation of telematics controllers to gauge engine operation is a powerful tool to reduce fuel use and carbon emissions and will allow the Division to measure progress toward its carbon emissions reduction goal in a near real-time manner.

Alternative Fuel Vehicles and Equipment

The most common source of carbon emissions in the Division of Maintenance and Development is the use of fossil fuels—gasoline, diesel, and propane—by vehicles and equipment. One of the most effective ways to reduce its carbon emissions would be to alter or replace certain fleet vehicles and equipment to use alternative fuel sources such as electricity, hybrid technology, or solar power.

Using lower fossil fuel sources allows for greater miles per gallon and generally lower emissions because the vehicle is not directly burning fossil fuels. Alternative fuel sources are more common amongst light- and heavy-duty vehicles, due to recent advancements in technology. However, there are viable options for heavy and large equipment to switch to alternative fuels to reduce emissions.

Light-Duty and Heavy-Duty Vehicles

The vehicle categories were categorized by primary use type, divided into light duty—small trucks, SUVs, and mid-sized sedans—and heavy duty—larger trucks, transport vehicles, and transit vans. Because these categories vary in their fuel consumption rates and usage, the emissions reduction strategies are based on individual categories instead of an overall vehicle policy.

Within the light duty category, the most important change to the current fleet is to replace old or outdated model vehicles with low- or zero-emission alternatives. The older vehicles include two Chevrolet Ventures (1999, 2004), G1500 (2000), G2500 (2005), and GMC Savana (2006) as well as two SUVs, a Chevrolet Blazer (2000) and three GMC Savanas (2008). These vans and SUVs have generally lower mile-per-gallon consumption rates than new versions of the same models, as well as had some of the lowest city mileage values.

In addition, these older vehicles are the most likely to have decreased fuel consumption rates. Since much of the inventory was analyzed based on current fuel consumption data, mpg values must be taken with a grain of salt, as “real world” results will likely yield increasingly worse results. For example, one of the 2008 GMC Savanas was logged using 309.9 gallons of fuel in 2019, which would, under a worst-case 12 mpg scenario, provide approximately 3,720 miles of transportation. However, that 2008 Savana actually only managed to travel 3,081 miles, with a calculated mileage of only 9.9 miles-per-gallon, over two mpg less than the lowest expected mileage. Using the average 2019 fuel price of $2.60 (US Energy Information Administration) and reverse calculating the cost of fuel for the missing miles by dividing the difference in expected and actual mileage by the cost of the fuel, this vehicle alone cost the Division around $245 in fueling costs in 2019.

By replacing the fleet's oldest light-duty vehicles, the Division will not only mitigate its annual carbon dioxide emissions but can also expect to see a decrease in the expected replacement cost/time ratio, as newer models are likely to improve actual mileage more than the inventory analysis indicates.

The second way to improve operations of light-duty vehicles is by regearing the trucks in this category. The Ford F150 is notorious for dropping mileage under city conditions, but other light-duty trucks, like the Chevrolet Colorado and Silverado, have the same problem. This is caused by the trucks' axle-gear ratios, a ratio of the motor gear to the driven gear. In general, gear ratios measure between 3 and 4.5, with lower ratios offering better mileage with lower torque, while higher ratios offer more hauling capacity but also the downside of losing mileage. Manufacturers often try to use a "medium" gear ratio for retail models, which allows for decent city/highway mileage but doesn't allow for improvement in either hauling or milage.

Trucks in the Division's fleet used exclusively for highway or city driving should be considered for regeared drive trains. For trucks designated for city driving and hauling equipment/materials, changing the drive train to a higher gear ratio would provide more torque when hauling heavy loads, as well as better acceleration in stop-and-go conditions. Alternatively, for trucks used primarily for longer distance hauling and transportation, regearing the drive train to a lower gear ratio would allow them to achieve better mileage on long trips at the cost of lower torque and slower acceleration.

Because of variations in range, cargo load, operations, and general use for large and heavier duty vehicles, a single solution isn't possible. A suggested strategy for reducing emissions from heavy-duty vehicles would begin by replacing the oldest fleet vehicles with alternatives powered by electric or hydrogen batteries. Most low-emissions alternatives for heavy-duty vehicles are still being developed. Due to the increased interest in vehicles with cleaner fuel usage, the 2020s are slated to see the release of a wide variety of electric, zero-emissions alternatives. Additionally, many companies are planning hydrogen powered heavy-duty vehicles production in the late 2020s (Nikola, 2020). The upfront investment to replace heavy-duty fleet vehicles is substantial but given the high cost of fueling these large vehicles with long range usage and low fuel economies, the savings on fuel are significant. For instance, the following replacements would generate immediate emissions reductions:

- Replace one of the Division's Freightliners, such as inventory item T139, a 2011 Freightliner M2112V, which is one of the fleet's older large transport vehicles. This vehicle produced over 15MT of CO_2 in 2019; replacement would cost between \$150,000 and \$200,000. Tesla states that because the cost of electric energy is half the cost of diesel and much less maintenance is required for these vehicles, "the Tesla Semi can provide \$200,000+ in fuel savings and a two-year payback period" when compared with a standard diesel semi (Tesla, 2020). The Division spent almost $18,000 on the maintenance, repair, and fuel costs of this vehicle in 2019 and replacing it would instantly eliminate direct CO_2 emissions in this vehicle's operation.

- Likewise, it's worth replacing inventory items such as the T038, a 2010 Freightliner FLD120SD, which appears to have gotten less than five miles-per-gallon. Its operation resulted in nearly 4 MT of CO_2 despite being driven only 1,886 miles in 2019.

The five vehicles in the fleet that produce the most CO_2 emissions account for 10 percent (91.4 MT CO_2) of the total emissions produced in 2019. Replacing these five vehicles—three 2014 Freightliner 114SDs (T195, T569, and T542), one 2011 Freightliner M2112V (T139), and one 2008 Ford F350 (T097)—with reduced or zero emissions alternatives would result in immediate progress toward the Division's reduction goal for 2030.

By focusing on the top ten vehicles with the highest emissions, 16.3 percent (148.4 MT) of the inventory's CO_2 emissions could be mitigated. These five additional vehicles are a 2016 Kenworth T370 (T029), 2014 F350 (T562), 2019 Freightliner M2106 (T211), 2015 F550 (T479), and a 2008 F350 (T231).

Aside from replacing the fleet's heavy-duty vehicles that produce the most CO_2 emissions, maintenance and use practices are a slower way to implement CO_2 reductions. One area to target would be the vehicle's aerodynamic characteristics. Studies by the European Union initiative *Reducing CO_2 Together* show that retrofitting larger vehicles with low-rolling resistance tires is low-cost and can increase fuel efficiency by up to four percent. Additionally, more extensive driver training can reduce CO_2 emissions by up to seven percent (*Reducing CO_2 Together*, 2017).

Without completely replacing the fleet's heavier duty vehicles, using second-generation biodiesel can double the efficiency of standard diesel, increasing emissions reductions as this technology continues to evolve (*Reducing CO_2 Together*, 2017). The CO_2 emissions of mobile combustion sources that run on 100 percent biodiesel are currently 9.45 kg per gallon of fuel consumed, so the transition to this alternative fuel could initially decrease emissions from diesel vehicles by almost 10 percent while offsetting a large portion of the emissions from the fuel production process (U.S. Environmental Protection Agency, 2014). Diesel vehicles are responsible for 427 MT of CO_2 in the inventory, so with a best-case scenario reduction of nearly 10 percent through biodiesel, emissions could be decreased by 42.7 MT CO_2.

Table 2: Specific Vehicle Fleet Replacements

Vehicle Used by Maintenance & Development Division	Potential Replacement Vehicle	Alternative Vehicle Release Year, Specs, Price	Total Emissions Reduction
Freightliner Semi Trucks	Tesla Semi Trucks (Tesla, 2020) Freightliner eCascadia Trucks (Freightliner, 2020)	two vehicle ranges: 300-mile range (base model $150,000) 500-mile range (base model $180,000) runs on electric battery and energy consumption is less than 2 kWh per mile first Tesla Semis will be delivered in 2021	replacing all inventory Freightliners with lower emissions alternatives could reduce CO_2 emissions by up to 126.5 MT
Sprinter Vans	Mercedes Benz eSprinter (Bruce, 2019) All-electric Ford Transit cargo van (Hawkins, 2020)	eSprinter: 2020 European release, US release TBD Ford Transit: 2022 US release, at expected cost of $45,000; buyers eligible for $7,500 federal electric vehicle tax credit	eventual conversion of all sprinter vans would reduce direct CO_2 emissions by 50.5 MT
Large Trucks (Ford F-250, F-350, F-450, F-550)	Hybrid or electric Ford F-250, F-350, F-450, F-550 (Colley Ford, 2020)	expected hybrid and electric launch and of F-Series trucks, starting with the F-150 in 2021	eventually replacing all large fleet trucks with hybrid or fully electric versions, could reduce CO_2 by up to 199.6 MT

Large and Small Equipment

A key part of reducing the Division's equipment carbon emissions would be switching to alternative fuel sources for many of the fleet's large emitters. Large equipment, such as bulldozers, excavators, and crawlers, use diesel fuel as their primary fuel source, which emits more CO_2 per gallon compared to standard gasoline engines. Unfortunately, due to the high horsepower and engine requirements of large construction equipment, electric and hybrid alternative fuel sources are not readily available; they would not be powerful enough.

However, biodiesel is alternative fuel source for large equipment. (Biodiesel is obtained from various plants and animals rather than fossil fuels.) When used in excavators, “B100 biodiesel emissions are still 74% lower than those from petroleum diesel … [and] It is reported that no modifications need to be done to operate an excavator on the alternative fuel.” (Abolfathi, 2019). Another report found that, “For each megajoule (MJ) of biodiesel produced 0.041 kg of GHG CO_2 equivalent is released. For each MJ of fossil diesel produced 0.095 kg of GHG CO_2 equivalent is released.” (Systems et al., 2006). Biodiesel can be effective in reducing the emissions of diesel-based equipment without needing to buy new equipment. If biodiesel is readily available, it is the most promising alternative fuel to reduce CO_2 emissions from for excavators, crawlers, forklifts, etc. while being relatively easy to implement.

Mowers account for 89.7 percent of the carbon dioxide emissions for the inventory’s small equipment. All of the mowers are fuel-powered: 62.5 percent use diesel, 29.2 percent use gasoline, and 8.3 percent use propane. One way to reduce their direct CO_2 emissions is to switch to electric equipment. Because electric mowers eliminate direct CO_2 emissions, switching to electric equipment can help reduce emissions within the small equipment category (California Air Resources Board, 2018; Eco-Equipment Supply, 2019).

If the zero-turn mowers were replaced with EVO-74” ZTR mowers, the walk-behind mowers replaced with WBX-33HD mowers, and the riding mowers replaced with Ryobi 38” riding mowers, CO_2 emissions would be drastically reduced. The total reduction of direct CO_2 emissions from converted mowers would be approximately 97 percent or 20 MT. The cost of switching to electric mowers would be about $491,000.

The remaining 10.9 percent of the CO_2 emissions come from one trail light, three utility vehicles, three generators, one stand-on aerator, and one spreader. The utility vehicles contribute to nearly half (47.3 percent) of the non-mower CO_2 emissions and use diesel fuel for operations. Replacing them with Cushman electric vehicles would reduce CO_2 emissions by approximately 47.3 percent or 1.1 MT. Switching to electric utility vehicles would cost about $43,000.

Continued Future Investment

To effectively reduce the Division’s carbon emissions by 50 percent from 2019 levels by 2030, numerous actions are needed, including establishing new, enforceable rules. As previously noted, there are multiple ways to reduce emissions from both vehicles and equipment, but the methods of reducing emissions need to be category specific (Figure 1) to be both efficient and effective. Most of the Division of Maintenance and Development’s carbon emissions are from vehicles, more specifically from heavy-duty vehicles. Therefore, emissions reduction strategies should be weighted toward reducing vehicle emissions, but still include methods to reduce emissions in other parts of the fleet. To effectively and efficiently achieve the carbon emissions reduction goal of 50 percent by the year 2030, two strategic options are described below.

Option 1: 3-step strategy

- Reduce idling
- Plan and select work for efficiency
- Transition to biodiesel for all or most heavy equipment and vehicles

The first step to reduce emissions is to shift the Division's everyday practices, specifically the work of the fleet managers and operators. Often, vehicles and equipment are operated inefficiently for fuel use and emissions production. This can be changed by instilling an atmosphere where the operators of the fleet vehicles and equipment consciously make an effort to reduce fuel consumption of the Division's inventory. This can be accomplished by monitoring and enforcing the operation of vehicles and equipment to have minimal idle times and reminding drivers to accelerate and brake slowly.

Another practice to implement is efficient work scheduling and selection of vehicles and equipment for their designated duty. For example, the inventory includes a Caterpillar 323TC excavator with 172 HP and a Bobcat E85 excavator with 66 HP. When planning work schedules, a job that doesn't require high intensity excavating, the Bobcat should be used rather than the Caterpillar because its large engine uses more fuel and provides more horsepower than necessary for the job. As a best practice, heavy equipment should only be on when actively working on a task to reduce idling and emissions.

The final step would be to replace or reduce the use of diesel fuel. Biodiesel is an ideal alternative because it generates significantly less CO_2 emissions per unit of fuel. It produces roughly half the amount of CO_2 emissions per gallon than standard diesel fuel, so if the Freightliners and large equipment such as bulldozers and crawlers can switch to biodiesel fuel, this will significantly reduce fleet emissions. This change wold allow the Division to begin reducing CO_2 emissions to achieve a 50 percent reduction by 2030.

Option 2: 4-Phase Strategy

- Reduce idling
- Plan and select work for efficiency
- Install telematic equipment
- Invest in electric and hydrogen heavy vehicles, mowers, and utility vehicles

To implement Option 2 the Division would being by implementing the Option 1 strategies. The first two—reduce idling and plan work for efficiency—are crucial to achieving a 50 percent reduction.

The next step is to install telematic equipment on all fleet vehicles and equipment to measure real-time the fuel consumption and CO_2 emissions. Telematic equipment can be modified to automatically cut fuel consumption by reducing top speeds, idling, and transmission RPMs, which will reduce emissions and fuel costs. The telematic equipment data will also allow the Division to continue to maximize the fuel efficiency of vehicles and equipment, and to better analyze and reduce carbon emissions using the telematics into the future.

The final Option 2 step is to invest in alternative-fuel vehicles and equipment. As shown in the analysis, vehicles account for most of the Division's emissions and thus offer the greatest opportunity to reduce CO_2 emissions. Initial efforts should begin by phasing out old, low-use, and inefficient vehicles, such as the 2010 Freightliner FLD120SD, which achieves less than five miles per gallon, generating nearly 4 MT CO_2 despite being driven only 1,886 miles in 2019. This vehicle should be phased out and replaced with an electric alternative such as the Tesla Semis, which are completely electric and will not increase CO_2.

The investment in alternative-fuel vehicles and equipment should be a continuous, long-term process to ensure emissions targets are achieved by 2030 without undue upfront costs to the County. Investment in electric mowers and utility vehicles to replace the fuel-powered mowers and utility vehicles can contribute to reducing the Division's emissions. If done correctly, Option 2 will effectively reduce carbon emissions by 50 percent by 2030.

Conclusion

In response to county and state level initiatives to reduce greenhouse gas emissions, the Prince George's County Department of Parks and Recreation, Division of Maintenance and Development has set a goal of reducing emissions by 50 percent from 2019 levels.

To determine the Division's 2019 CO_2 emissions, two assumptions were made for equipment lacking fuel consumption data. First, the age of inventory items had no effect on fuel consumption rates and that items were in near-perfect condition when being operated. In practice, engine efficiency varies across inventory items, so fuel consumption rates may be higher; equipment may have been used by the Division for years or hasn't been maintained to manufacturer recommendations.

The second assumption was that fuel consumption rates for small equipment (with spark-plug engines) were set for use in dry conditions and across relatively flat landscapes. Field conditions can affect CO_2 emissions. Hilly landscapes or wet conditions may cause the mower to use more fuel to complete a task. The influence of these factors on emissions is difficult to determine and makes calculating the emissions more complex. It's important to be aware of how these assumptions might limit the accuracy of this project's estimated CO_2 emissions baseline.

The results of the compiled CO_2 emissions calculations show that the Division of Maintenance and Development produced 909.3 MT of CO_2 between January 1, 2019 and January 1, 2020. Of these emissions, 66.8 percent were produced by the Division's vehicle fleet, and 33.2 percent were produced by large and small equipment.

To achieve a 50 percent reduction by 2030, emissions would need decrease by 454.7 MT of CO_2 in the next ten years. If reduced equally each year, this would require an annual 45.5 MT reduction. To put this into perspective, in 2014, Prince George's County produced an estimated 4.39 million MT of CO_2 vehicle emissions (Maryland Department of Energy, 2016). While this may make the Division's emissions seem less significant, it is important to note that most of the County's emissions come from residential and commercial sources, over which the state and county have less control. Therefore, internal emissions reduction efforts are imperative; they are the most accessible in this timeframe and will set a demonstrative model that influence other major emissions sources.

Based on these findings, the Division of Maintenance and Development should pursue Option 2: a 4-phase strategy that is more effective at meeting the 50 percent reduction goal and preparing the Division to further reduce CO_2 emissions beyond 2030. If the Division maintains consistent fuel consumption records, it will be able to more accurately calculate a carbon emissions baseline and track the progress of reduction efforts.

Additionally, with continued research into alternative fuel types and other emissions sources, such as buildings, the Division can reach carbon neutrality and contribute toward Prince George's County's goal of an 80 percent reduction of 2008 carbon emissions levels by 2050 (Bannerman n.d).

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Appendix 1. Actual vs. Estimated Vehicle Emissions

Comparison of Calculated Vehicle CO_2 Emissions from Fuel Logs vs. Vehicle Emissions Calculations from Published and Observed Fuel Economy

Vehicle VINs were used to determine the fuel type of each vehicle, The EPA's Fuel Economy website was then used to retrieve fuel economy data for each passenger vehicle. Mile per gallon data for larger vehicles, including Ford F-250s through F-550s, Freightliner M2106 trucks, and Mercedes Benz Sprinters, is not provided on the EPA website, and manufacturer booklets are not required to provide this information. To supplement this missing information, fuel consumption data was acquired from third party platforms when available. This process included directly establishing contact with manufacturers, finding equipment review websites, and in the case that none of the previous steps succeeded, extrapolating user reported data from online forums and blogs. Of the 100 vehicles in the inventory, research-based estimates of fuel economy and vehicle miles per gallon were found for 89 vehicles. Eleven vehicles were not included in this comparison.

Actual 2019 emissions for these vehicles were 518.7 MT CO_2, and estimated emissions using city fuel economy ratings and reported annual mileage were 602.8 MT CO_2 (Figure 14). Actual CO_2 emissions were only 86 percent of the estimated emissions, showing that using expected city mileage provides a conservative emissions calculation. This comparison reveals the general differences between manufacturer fuel economy ratings and observed vehicle fuel consumption with standard use. It shows the likely error range that could be expected in studies that derive CO_2 emissions amounts solely from EPA mileage data.

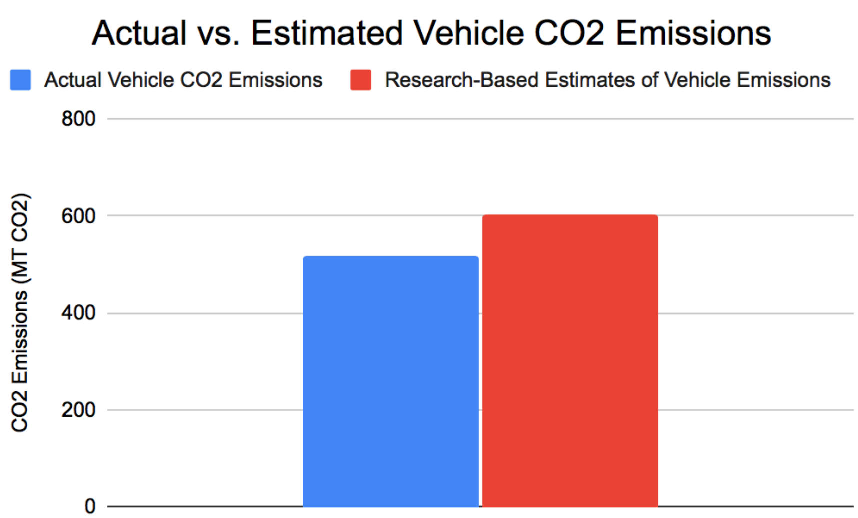

Figure 14: Comparison of vehicle emissions based on fuel usage logs vs. manufacturer, EPA, and customer observed fuel economy

Appendix 2. Inventory Spreadsheet

Inventory Spreadsheet Used to Determine CO_2 Emissions from Fuel Consumption

Online Link to Inventory Sheet:
https://docs.google.com/spreadsheets/d/e/2PACX-1vT1Ibjld-CXfk7gTWYElWwsoOuJFJCSg5vi6O-inZwetGanoHOgwqownRNVbLXfS5o3-M6LJQeFLnV9/pubhtml?gid=1484676785&single=true